Enhanced electron-beam-induced current contrast of grain boundaries in silicon-on-insulator films

Kuper, F. G.; de Hosson, J. Th. M. ; Verwey, J. F.

Published in:
Journal of Applied Physics

DOI:
10.1063/1.338239

Enhanced electron-beam-induced current contrast of grain boundaries in silicon-on-insulator films.

F. G. Kuper, J. Th. M. De Hosson, and J. F. Verwey
Department of Applied Physics, Materials Science Centre, University of Groningen, Nijenborgh 18, 9747 AG Groningen, The Netherlands

(Received 11 November 1986; accepted for publication 9 February 1987)

The direct electron-beam-induced current (EBIC) observation of electrical properties of grain boundaries in silicon-on-insulator (SOI) structures has always been hampered by the insulated structure to be measured. In this communication a new structure is proposed with which EBIC images of grain boundaries in as-grown SOI layers can be obtained. Implantation of fluorine in the layer causes an enhanced contrast of these boundaries.

Thin films of recrystallized silicon are of great interest as the basic material for thin-film transistors and for multilayer integrated circuits. However, grain boundaries in these layers may have detrimental effects on the operating characteristics of electronic devices both by introducing short circuits due to enhanced diffusion of dopants and by creating localized energy states which pin the Fermi level near the center of the band gap.

In order to minimize these effects one can try to increase the grain size in the film by, e.g., seeded growth using a stripheater,[1] or to passivate the energy states of the boundaries by hydrogenating the film after recrystallization, a method already used in polycrystalline silicon solar cell fabrication.[2] A disadvantage of stripheating is the prolonged heating of the film and underlying structures, which will flatten doping profiles especially by grain boundary diffusion. Therefore, the quick laser recrystallization process is more suitable for making three-dimensional structures. A disadvantage of hydrogen as passivator of the boundaries is that it diffuses out rapidly.[3] A more promising passivator in this respect is fluorine. Like hydrogen, it needs one electron to obtain a noble gas configuration. Moreover, it makes a stronger bond with a silicon atom, as can be concluded from the bond strengths of the diatomic molecules H-Si (3.1 eV) and F-Si (5.6 eV). Furthermore, it is well known that fluorine tends to be located near defects and interfaces.[4–6] However, there is some evidence based on temperature dependent electrical resistivity measurements[7] that fluorine introduces rather than passivates, states in the upper half of the band gap.

To study the electrical properties of grain boundaries after passivation one can measure overall quantities, like the resistivity along and perpendicular to a grain boundary,[7,8] but one really wants to locally measure a quantity related to the energy states due to a grain boundary. Electron-beam-induced current (EBIC) is measured with a resolution between 1 and 10 μm depending on beam energy and material quality.[9,10] EBIC combines defect observation with an electrical measurement, because the intensity displayed on the screen corresponds to the local recombination of excess electron/hole pairs. The difficulty in the study of SOI structures, however, is that we have an insulated layer of silicon, so a backside contact to a simple Schottky diode cannot be used. EBIC studies of silicon-on-insulator (SOI) structures therefore make use of lateral *pn* junctions,[11–13] or field-effect transistors of which the electron beam induced gate to channel current, which depends locally on the silicon layer potential, is used as the video signal.[14,15] However, the imaging contrast obtained so far was quite poor.

We report a new measuring device for EBIC evaluation of SOI structures, the double Schottky, which is depicted schematically in Fig. 1. The main advantage of this structure is that the recrystallized layer can be studied as grown because there is no need to diffuse a *pn* junction. The junction operates as follows: under either one of the metal contacts a region is depleted, depending on the sign of the applied voltage. In these regions electron hole pairs generated by the electron beam are separated by the electric field, thus contributing to the EBIC current. Variation in recombination time and depletion width near grain boundaries yields the EBIC contrast. The EBIC image can also be influenced by varying the backside voltage, the backside being used as a gate.

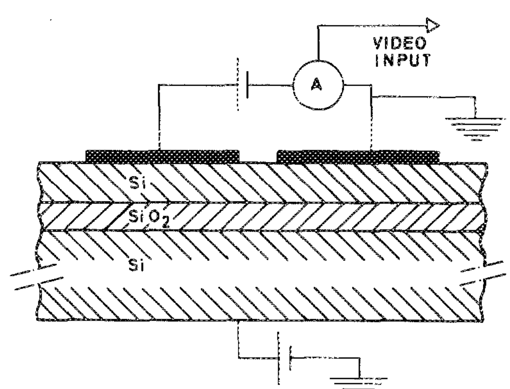

FIG. 1. Schematic illustration of the double Schottky diode in a SOI structure and of the EBIC circuitry used.

 0021-8979/87/125475-03$02.40

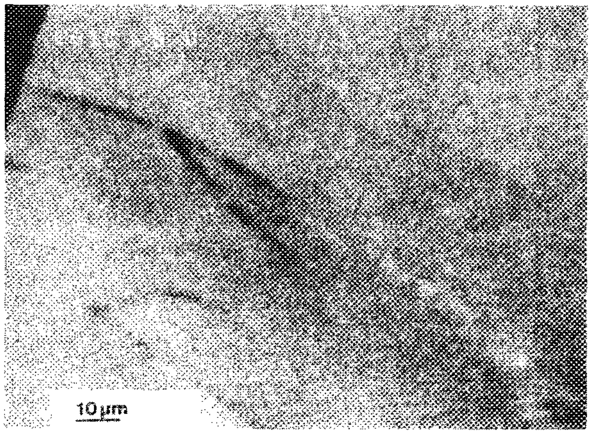

FIG. 2. EBIC micrograph of grain boundaries in a SOI structure.

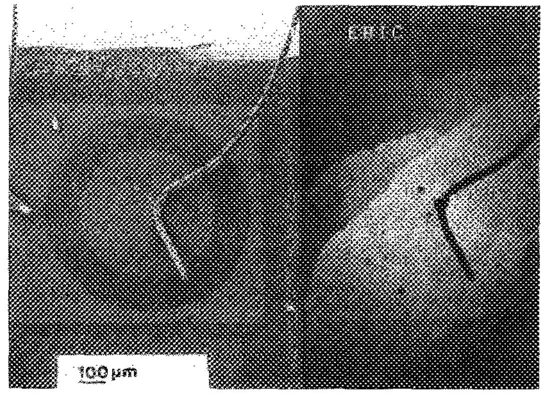

FIG. 4. Combined SEI and EBIC micrograph showing the difference in contrast between subgrain and grain boundaries.

For our recrystallized samples we used sputtered titanium as the contact metal. Before recrystallization the undoped silicon layer was about 1 μm thick, the underlying oxide layer about 0.5 μm, and the encapsulating oxide 1 μm. For recrystallization a halogen lamp system was used comparable with Vu, *et al.*[16] With the double Schottky structure, grain boundaries could be observed under the contacts as expected. The contrast, however, was poor (see Fig. 2).

After an implantation of 5.10^{15} F^+ ions/cm^2 at 30 keV, a subsequent anneal at 575 °C for 15 min and titanium deposition (90 nm), the double Schottky's displayed a remarkably strong contrast in the EBIC mode, as depicted in Fig. 3.

The aluminum contact can be seen clearly in both secondary electron image (SEI) and EBIC image. The titanium can hardly be seen in the EBIC image, but both grain and subgrain boundaries can be observed clearly even in the region where no titanium is deposited.

The difference between the images of a grain boundary and a subgrain boundary is that at the former the overall intensity changes, whereas at the latter only a signal at the boundary itself is observed. A typical example is shown in Fig. 4.

Figure 5 is an EBIC image with the same magnification as Fig. 2. The enhanced contrast due to the fluorine implantation is apparent comparing Figs. 5 and 2. On the faceted boundary near the arrow, one notices a few electron beam induced microplasmas.

In order to distinguish between implantation effects and the effect of the implanted (passivating) fluorine, a SOI structure similar to the ones used before, was implanted with neon ions. Implantation of 5×10^{15} ions/cm^2 at 30 keV and subsequent anneal as previously mentioned, resulted in an EBIC contrast as depicted in Fig. 6. Hardly any EBIC contrast between the Schottky contacts could be detected, but underneath two types of contrast have been imaged. Some regions exhibit a large offset EBIC signal (positive under one contact and negative under the other) but all regions display an image in which the morphology of the recrystallized layer can be seen. No electrical effects at grain boundaries were observed.

It is evident from the comparison of Fig. 6 with Figs. 3, 4, and 5 that the observed enhanced EBIC contrast after fluorine implantation is due not only to the implantation damage, but to the kind of implanted ion as well. The tentative explanation of the effect of implanted fluorine on the EBIC contrast is as follows: Greeuw and Verwey[17] showed that an implantation of 10^{15} F^+ atoms/cm^2 leads to *n*-type

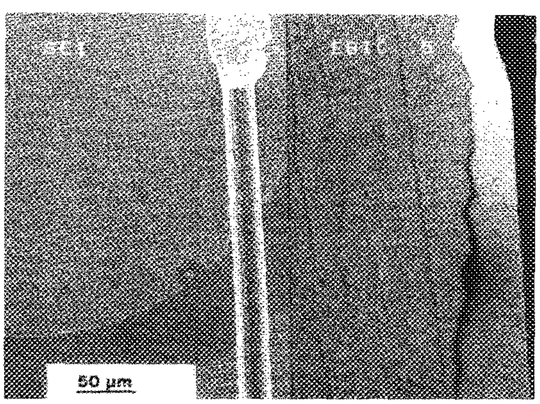

FIG. 3. Combined secondary electron image (left) and EBIC micrograph (right) of a SOI structure after fluorine implantation. One grain boundary and several subgrain boundaries can be seen in the EBIC micrograph.

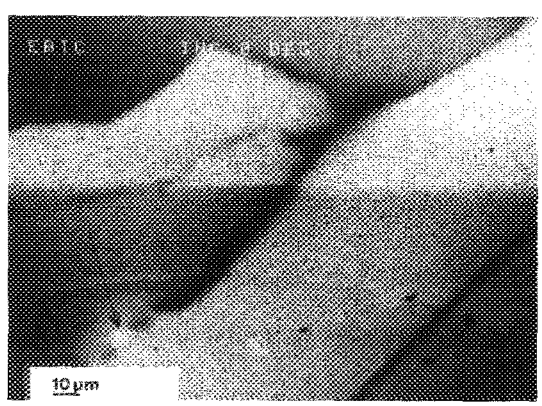

FIG. 5. EBIC micrograph of grain boundaries in a SOI structure. Arrow points at a microplasma. The titanium contact can be seen in the lower third of the picture. Same sample as depicted in Fig. 4.

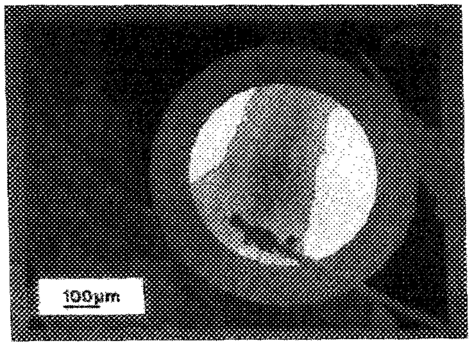

FIG. 6. EBIC micrograph of a SOI structure after neon implantation. The entire double Schottky diode is depicted.

doping in the implanted region even after a 1000 °C anneal. Apparently the implanted fluorine introduces donor states that are not removed after a high-temperature anneal. Goetzberger, Klausmann, and Schulz[18] reported two donor levels after fluorine implantation, 0.21 eV below the conduction band and 0.44 eV above the valence band, but only one donor level after neon implantation, 0.22 eV below the conduction band. Due to the states at 0.44 eV above the valence band, implantation of fluorine leads to a conductive (heavily damaged) layer within, or on top of the silicon layer. This layer is probably the reason that an EBIC image is observed outside the contacted regions as well. This conductive layer is divided into little areas by the enhanced barriers of the grain boundaries. The boundaries can cause a voltage drop from grain to grain; consequently, a grain boundary will mark an overall change in EBIC intensity. As subgrain boundaries do not separate two grains with a potential difference, this explains the difference in imaging of grain and subgrain boundaries.

The way fluorine is built in depends on the damage it decorates. Ginley[7] reported a complete return to the original state after an anneal at 800 °C, but after removal of the (most damaged) top layer an anneal at 400 °C was already sufficient. Therefore, in order to investigate the passivating properties of fluorine one should preclude implantation damage, thus preventing the persistent *n*-type doping to occur. This can be done, for instance, by means of diffusion from an oxide layer. On the other hand, if one wants to evaluate the electrical properties of grain boundaries in a SOI structure, one should introduce damage thereby creating a conductive layer under which the grain boundaries due to the increased barrier height can be imaged very well in the EBIC mode.

In conclusion, we may state that implantation with fluorine and subsequent anneal at 575 °C does not passivate the grain boundaries in a silicon film, due to the introduction of stable, damage related energy states in the upper half of the band gap, but that EBIC contrast of grain boundaries, due to this combination of doping and barrier increase, turns to advantage, resulting in an EBIC contrast greater than other methods could provide so far.

We like to thank J. B. Verburg for the recrystallizations and J. Adema for the EBIC measurements on neon-implanted SOI structures. This work was part of the Research Program of the Foundation for Fundamental Research on Matter (FOM—Utrecht) and has been made possible by financial support from the Netherlands Organization for the Advancement of Pure Research (ZWO—The Hague).

[1] J. C. C. Fan, B.-Y. Tsaur, and M. W. Geis, J. Cryst. Growth **63**, 453 (1983).
[2] C. H. Seager, D. S. Ginley, and J. D. Zook, Appl. Phys. Lett. **36**, 831 (1980).
[3] H. Fritzsche, M. Tanielian, C. C. Tsai, and P. J. Gaczi, J. Appl. Phys. **50**, 3366 (1979).
[4] M. Y. Tsai, D. S. Day, B. G. Streetman, P. Williams, and C. A. Evans, J. Appl. Phys. **50**, 188 (1979).
[5] M. E. Lunnon, J. T. Chen, and J. E. Baker, Appl. Phys. Lett. **45**, 1056 (1984).
[6] F. G. Kuper, J. Th. M. De Hosson, and J. F. Verwey, J. Appl. Phys. **60**, 985 (1986).
[7] D. S. Ginley, Appl. Phys. Lett. **39**, 624 (1981).
[8] E. W. Maby and D. A. Antoniadis, Appl. Phys. Lett. **40**, 691 (1982).
[9] J. Marek, J. Appl. Phys. **53**, 1454 (1982).
[10] H. J. Leamy, J. Appl. Phys. **53**, R 51 (1982).
[11] N. M. Johnson, D. K. Biegelsen, and M. D. Moyer, Appl. Phys. Lett. **38**, 900 (1981).
[12] H. Baumgart, H. J. Leamy, L. E. Trimble, C. J. Doherty, and G. K. Celler, in *Grain Boundaries in Semiconductors*, edited by G. E. Pike, C. H. Seager, and H. J. Leamy (Elsevier, New York, 1982), p. 311.
[14] H. J. Leamy, R. C. Frye, K. K. Ng, G. K. Geller, E. I. Povilonis, and S. M. Sze, Appl. Phys. Lett. **40**, 598 (1982).
[15] R. C. Frye and K. K. Ng, in *Grain Boundaries in Semiconductors*, edited by G. E. Pike, C. H. Seager, and H. J. Leamy (Elsevier, New York, 1982), p.275.
[16] D. P. Vu, M. Haond, D. Bensahel, and M. Dupuy, J. Appl. Phys. **54**, 437 (1983).
[17] G. Greeuw and J. F. Verwey, Solid-State Electron **26**, 241 (1983).
[18] A. Goetzberger, E. Klausmann, and M. J. Schulz, Crit. Rev. Solid State Sci. **6**, 1 (1976).